

Quantifying the Effectiveness of Fire Suppressants in a 1-D Laminar Diffusion Flame

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Introduction

In this study a method for evaluating and ranking fire suppressants is being developed. A small scale, stagnation-point flow apparatus has been constructed that can test a variety of gas and liquid suppression agents. This apparatus allows well controlled, transient experiments to be conducted on solid, liquid, or gaseous fuels. The one-dimensional, laminar diffusion flame configuration is convenient for experimental measurements and theoretical analysis. Experiments can be performed using various fuel types, oxidizer concentrations, and external heat fluxes. Supporting flame structure measurements, with and without suppressants, are performed using a steady counter-flow diffusion flame apparatus. These experiments along with numerical modeling will reveal and quantify physical and chemical suppression mechanisms. A better understanding of fire suppression mechanisms will assist in the selection of an optimal suppressant and application method for a particular environment. The results from these tests will also aid in finding halon substitutes by identifying important properties of fire suppressants.

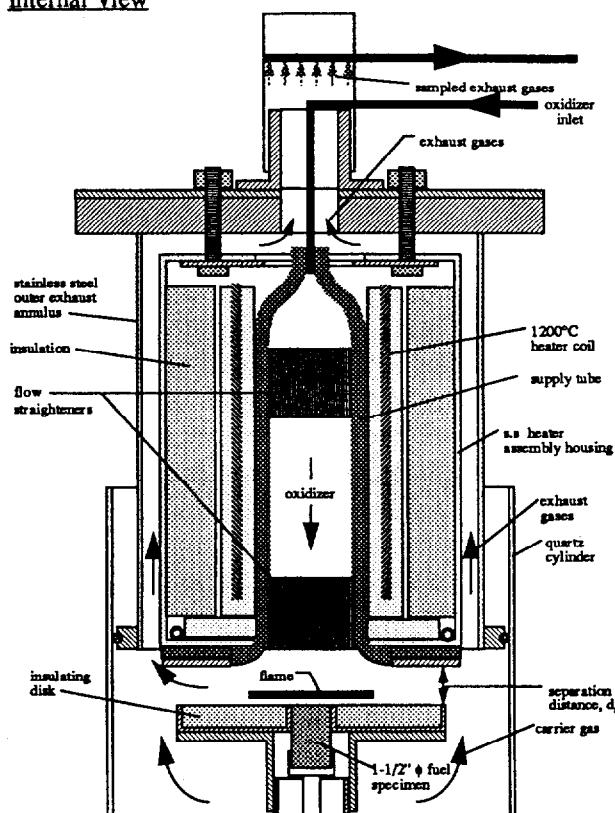
Initial experiments have been performed to evaluate the suppressing effects of liquid water since it is the most widely used and readily available agent. Water is considered to be a physical suppressant which utilizes its heat capacity, heat of vaporization, dilution and radiation effects to cool the flame or the pyrolyzing material. Our tests using PMMA and methane have shown, that under certain conditions, water addition actually enhances the combustion rate. This increase in energy output from the flame indicates that water can have chemical as well as physical effects on flames. These results suggest that more complete information is needed on fire suppressants and their suppression mechanisms.

Experimental Approach

The stagnation-point flow apparatus was used to obtain the results described in this paper. An internal and external view of this apparatus is shown in Figure 1. The oxidizer flows through a supply tube above the fuel source. This flow impinges on a flat plate producing a stagnation-point flow. The oxidizer can be preheated up to 1200°C by heating coils surrounding the supply tube. The flow straighteners installed inside the tube increase the heat transfer between the tube and the oxidizer and also eliminate radial components in the flow. Solid fuels such as PMMA or wood are supplied by a lifting mechanism which feeds the material through the center of the flat plate into the reaction zone as it is burned. Gaseous fuels are supplied through a porous burner embedded with thermocouples. Liquid suppressants are applied to the center of the fuel source through a water-cooled stainless steel probe.

The exhaust gases from the flame travel radially outward from the reaction zone and then up through an outer annulus into an exhaust tube. A carrier gas is used to transport the combustion

Internal View



External View

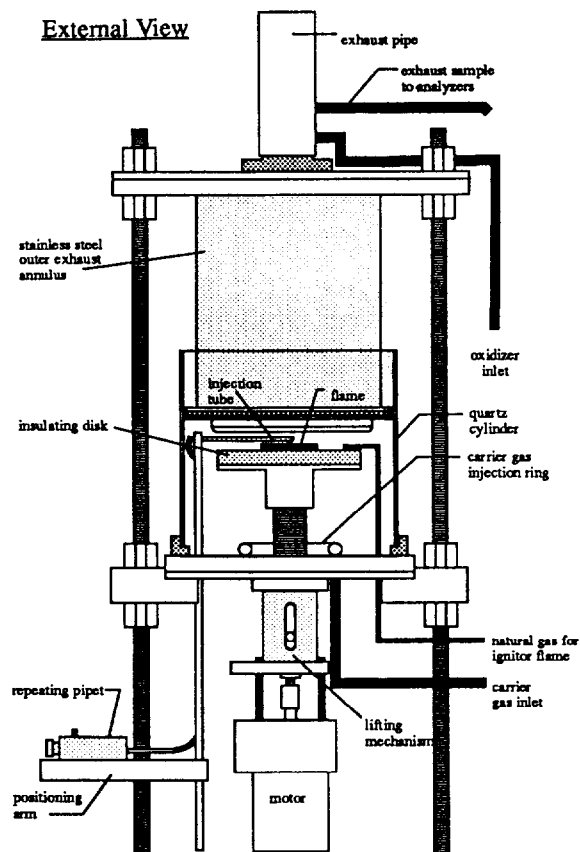


Figure 1: Internal and External Views of the Stagnation-Point Flow Apparatus

products to the sampling port and dilute them to prevent water condensation. Gas sample is continuously drawn from the exhaust tube, filtered for soot, and supplied to the gas analysis instruments. The combustion products are measured for total hydrocarbons (given in equivalent methane concentration), carbon dioxide, carbon monoxide, oxygen, and dew point. This data is then adjusted for time lags between the flame zone and the instruments. Each exhaust gas is also corrected for the response characteristic or transfer function caused by mixing in the exhaust and the inability of the instrument to respond to immediate changes in gas concentrations. The processed data in the final form gives gas concentrations coming out of the flame zone at the time they were generated.

Experimental Results

The initial tests in this study were performed on solid PMMA fuel samples using liquid water as the suppressant applied in small streams to the center of the burning solid. The feed rate of the PMMA was experimentally adjusted for each test condition until a steady output was observed in the combustion products and the liquid phase PMMA surface was level with the surface of the insulating disk (flat plate). Once steady-state conditions were achieved, a dose of water was applied to the PMMA using a step-syringe. Interesting results were obtained in the CO_2 production where a large increase occurred after the water application. An example of this result is shown in Figure 2 for a 0.5 ml water dose. This result was obtained using a PMMA feed rate of

1.1mm/min, 10.5 lpm oxidizer flow at 12% oxygen, 0.43 W/cm^2 external heat flux on the PMMA surface, and $d_s=0.5$ inches (refer to Fig. 1). The water was applied to the sample from above the flame with the step-syringe. It was found that CO_2 production initially increased considerably followed by a slight reduction. This remarkable effect cannot be explained by physical properties of water. Clearly the water is having a chemical enhancement effect on the flame. In this case, the chemical enhancement effect dominates the physical suppressing effects for approximately 25 seconds while the water evaporates from the solid surface. The physical effects then take over for 50 seconds as the cooled sample returns to an evaporating liquid phase. The enhancement effect was negligible for water applications less than 0.25 ml. However, water doses in excess of 0.6 ml extinguished the flame.

In order to distinguish between the chemical and physical effects of water, experiments were performed using a gaseous fuel supplied through a porous burner. The fuel supply in these tests was regulated using a mass flow controller which is not affected by the application of water as with solid or liquid fuels. For these gas tests, the suppressant injection probe was placed directly on top of the burner to reduce effects on the flame. These experiments also revealed the chemical enhancement effects observed in the PMMA tests. Figure 3 shows one such experiment where 36.5 mg/s of water was applied to the porous surface from 350 to 750 seconds using a motor driven syringe. The fuel supply was 1.5 lpm of natural gas, the oxidizer flow was 10 lpm with 21% O_2 , the external heat flux was 0.6 W/cm^2 , and again $d_s=0.5$ in. These settings were chosen to produce a sooty flame as observed in the PMMA tests. The CO_2 production in this experiment increased by 20% while the water was being applied. This is a very significant increase, but not as much as observed with the PMMA suggesting that the effect may be dependent upon the fuel type. Other notable features in Figure 3 are that the CO production decreased and the total hydrocarbons (THC) increased during the application of water. These results suggest that the water may be enhancing the flame by oxidizing some of the CO and inhibiting soot formation. The rest of the fuel that was going to soot production simply escapes as unburned hydrocarbons.

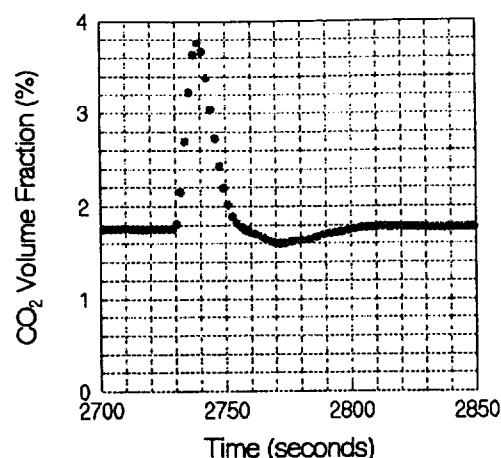


Figure 2: Effect of 0.5 ml liquid water on burning PMMA at 12% O_2

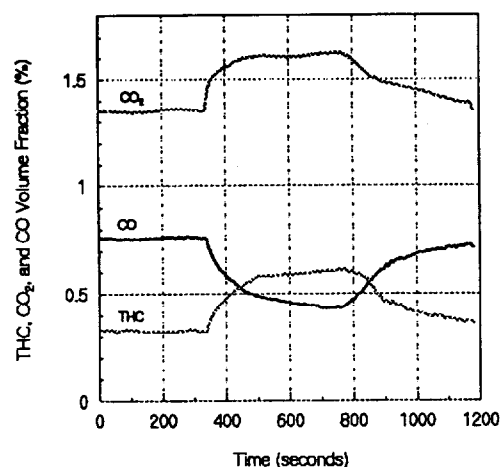


Figure 3: Effect of 36.5 mg/s liquid water on methane flame at 21% O_2

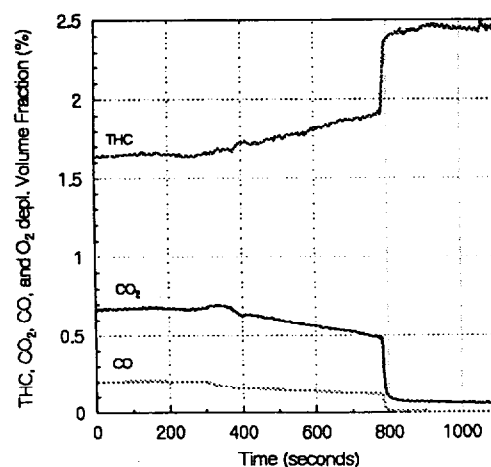


Figure 4: Effect of 36.5 mg/s liquid water on methane flame at 10% O_2

Other gaseous fuel experiments revealed that the effect of water is greatly dependent upon the oxygen concentration. At low oxygen concentrations, the flame is blue and the water simply suppresses the flame. An experiment showing suppression action leading to extinction is presented in Figure 4. Conditions for this test were kept the same as in Figure 3, except the oxygen concentration was reduced to 10% in the oxidizer flow and the water was applied from 300 to 900 sec. At this low oxygen concentration, the flame was blue, and no soot production was observed. In this experiment it is easy to see the suppression rate indicated by the rate of change of gas concentration while the water was applied, and the time of extinguishment just before 800 seconds.

Experiments at 30% oxygen concentration, with all other conditions held the same as in Figures 3 and 4, did not show enhancement effects for the same water flow rate. In fact, enhancement could only be observed for small amounts of water and were not very significant changes as in the 21% O₂ case. These experiments show that the enhancement effect does not keep increasing with oxygen concentration. It is important to note that the flame with 30% O₂ concentration oxidized nearly all of the fuel to CO₂ and H₂O, resulting in very little excess hydrocarbons and low levels of CO and soot.

Discussion

The experiments using liquid water demonstrate that water can have chemical as well as physical effects in a flame. Unfortunately for fire suppression, the chemical effects have been found to enhance the flame rather than inhibit the flame as with halon suppressants. Interestingly, the chemical enhancement effects of water were only observed for flames with significant soot and CO production. The low oxygen concentration tests had a lot of excess fuel, but very little CO and soot formation. The high oxygen concentrations burned nearly all of the fuel and also had very little CO and soot formation. Neither of these high or low oxygen conditions demonstrated chemical enhancement effects by water addition. However, when there was significant CO and soot production as in Figures 2 and 3, the flame could be enhanced by certain amounts of water. This finding is very important for fire safety since most fires have incomplete combustion and produce large amounts of soot and CO. The chemical enhancement effects of water are probably not observed previously because large quantities of water are used to extinguish fires.

This investigation shows that a better understanding of fire suppression and the effect of suppressants in a flame is needed. In order to develop new suppressants, we must identify which properties most effectively suppress flames as well as those which produce undesirable effects. The results of this work should help in selecting the best suppressant and the application technique for a given situation.

Acknowledgment

This research was supported by the Department of Commerce, National Institute of Standards and Technology, Center for Fire Research under Grant No. 60NANB2D1293. The construction of the stagnation-point flow apparatus was done by Peter Caffrey who also did preliminary testing for this work.